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GEOPHYSICS.—*The tides on the north Siberian shelf: their bearing on the existence of land in the Arctic Sea, and their dynamics.*[1] H. U. SVERDRUP. (Communicated by W. J. PETERS.)

The study of the Arctic tides attracted wide attention when the late Dr. Rollin A. Harris of the United States Coast and Geodetic Survey in 1911 concluded from his investigations that there was an extensive area of land within the unexplored area of the Arctic region. This conclusion was contrary to that of Fridtjof Nansen whose studies of the oceanography of the part of the Arctic Sea which he traversed with the FRAM during 1893 to 1896 had led him to believe in the existence of a deep polar basin.

Since Harris' conception became known the hypothetical Harris Land loomed before the eyes of the explorers who made it their task to solve one of the last of the geographical riddles of the globe, but their search was fruitless. McMillan, on his Crocker Land Expedition, and Stefansson, on his remarkable journeys over the sea-ice north of Alaska, both touched the outskirts of the unknown region without finding anything but broken sea-ice. Apparently Harris was wrong in his conclusion. However, the available data from the wide region west of Alaska and from the great north Siberian shelf were very scanty in 1911; there was practically only one tide-station, viz., Bennett Island. It was chiefly from the observations at this station that Harris drew his bold and far-reaching conclusions. Since 1911 new information has been gathered from this region, mainly through the work of the MAUD expedition in the years 1918–1925. The MAUD spent four years at various places on the coast of northern Siberia and drifted for two years with the ice distant 400 miles from the coast.

[1] Presented before the Philosophical Society of Washington, October 2, 1926. Received for publication Oct. 13, 1926.

The investigation of these observations combined with the earlier data indicated a tidal wave differing entirely from that deduced by Harris and led to the conclusion that the tidal phenomena do not indicate the existence of any extensive masses of land within the unexplored area. This conclusion was first mentioned in a radio message from the MAUD in 1923 and was further confirmed by the observations in 1924–1925. It was proved to be correct when in May 1926, Captain Amundsen, Lincoln Ellsworth, and General Nobile crossed from Spitzbergen to Alaska in the dirigible NORGE and passed over the central part of the unexplored area without seeing any land.

Figure 1 shows the available data for conditions at spring-tide for the entire region; spring-tide conditions were used since the most

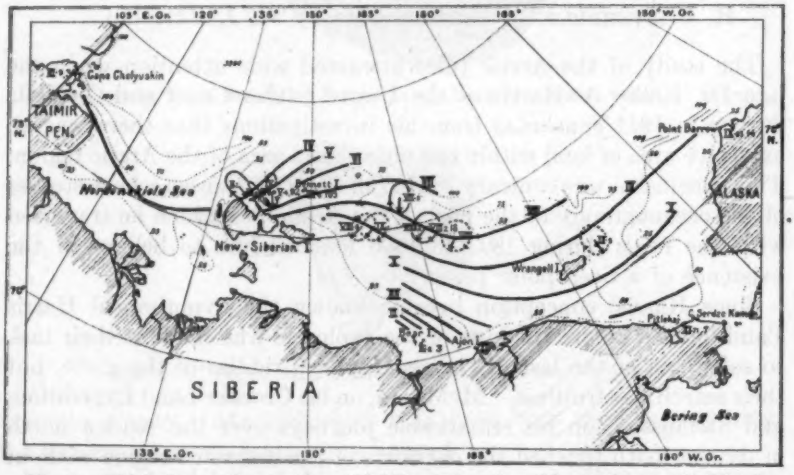

Fig. 1.—Tidal observations and co-tidal lines at spring tide on the north Siberian shelf.

reliable observations on the open shelf are obtained around spring-tide, when the difference between high-water and low-water is greatest and the tidal currents are most strongly developed. The earlier data indicated were obtained at Point Barrow (Alaska), Pitlekaj, and Bennett Island, while all the others result from the work of the MAUD expedition. The MAUD work was at the coast stations Cape Chelyuskin, Bear Islands, and Ajon Island, at three offshore stations where the time of high-water and the rise of the tide were determined by soundings, and at nine stations where the tidal currents were examined. The directions of the maximum tidal currents at spring-tide are plotted as arrows and the times of maximum current are expressed

in Greenwich lunar time. The characters of the tidal currents are indicated by ellipses, meaning that the currents are rotating; the directions in which the currents rotate are indicated by arrowheads. The ratio between the axes of each ellipse is equal to the ratio between maximum and minimum currents. The ellipses when full drawn represent the mean current from the bottom to the surface; when dashed they represent the current at selected levels. The time of high-water is given at all stations in terms of Greenwich lunar time. A line joining the points where spring high-water occurs at the same Greenwich lunar time represents the crest of the tidal wave at this particular time, a co-tidal line at spring. These lines, furthermore, have been drawn so that they run perpendicular to the directions of maximum currents. The heavy black lines represent the co-tidal lines drawn according to these rules. They represent the observations in a very satisfactory way and it can not be doubted that the co-tidal lines in this figure actually represent the front of the tidal wave at the stated hours.

What conclusions can be drawn from this picture regarding the existence or non-existence of land within the Arctic? Harris from his discussion concluded that the tidal wave proceeded from Bennett Island to Point Barrow, that is, practically from west to east and that this course necessitated the existence of an extensive area of land. Our result shows that the wave does not proceed from west to east but that it enters the entire region from the north. The tidal wave has the same character as the tide of the northern Atlantic. Therefore it can not be doubted that the tidal wave from the northern Atlantic enters the opening between Spitzbergen and Greenland and crosses the Arctic Sea without meeting any obstruction formed by extensive masses of land. However, no definite conclusion can be drawn that smaller islands may not exist. The figure reveals the striking fact that the tidal wave reaches the region of De Longs Islands five hours before it reaches Point Barrow though the direct distance from the Spitzbergen opening is nearly the same in both cases. This would indicate strongly that the sea is more shallow between Point Barrow and the Pole than between De Longs Islands and Spitzbergen, indeed perhaps so shallow that we might expect islands in places; however, any such conclusion may not be definitely drawn because we do not know enough about the progress of a long wave across a deep sea. The only certain conclusion, therefore, is that no extensive masses of land exist and this conclusion has already been verified by the results of the flight of the NORGE.

The co-tidal lines in our figure combine, as already mentioned, all observations in a satisfactory way and, together with the curves showing the motion of the water-particles, give a complete picture of the wave which enters the shelf from the north. In dealing with the tidal waves on the continental shelves one may neglect the direct action of the tidal producing forces, because this is proportional to the body of water upon which the forces act and the body of water on the shelves is negligible compared to that of the large oceans. Generally it is assumed that the tidal waves proceed across the continental shelves under the action of gravitational forces only. However, the picture in Figure 1 deviates greatly from that of a long wave proceeding under the influence of gravitational forces only. Attention may be drawn to the main characteristics as follows:

(1) The tidal currents do not run alternatingly in the direction in which the wave proceeds or against this direction but within the whole region they rotate clockwise. Over the open shelf there is very little difference between the strongest and the weakest currents, but where the wave runs parallel to a coast the currents are almost alternating.

(2) The currents are not uniform from the bottom to the surface. This is not evident from the entries in this figure, but we shall later return to this very important fact.

(3) The velocity of progress of the wave does not stand in the simple relation to the depth which is characteristic for a gravitational wave.

(4) The range of the wave varies within wide limits, from 210 cm. north of the New-Siberian Islands to only 3 cm. at Bear Island. A closer inspection shows that the range varies both along and perpendicularly to the wave-front. Referred to the direction in which the wave proceeds the range decreases from right to left, from 210 cm. to 14 cm. between the New-Siberian Islands and Point Barrow andit also decreases in the direction of progress, for instance from 18 cm. 400 miles off the coast to 5 cm. at Ajon Island and to 3 cm. at Bear Island.

All these features can be explained if the effect of the forces of inertia arising from rotation of the Earth and the resistance due to the eddy-viscosity are taken into account. I shall show how this can be done in the present case.

The upper left equations in figure 2 represent the hydrodynamic equations for a long gravitational wave. The X-axis of the coordinate system has been placed in the direction of progress of the

wave, and u and v represent the velocities of the water-particles in and perpendicular to the direction of progress, respectively. The elevation of the wave above the normal level is called ζ, the depth is called h, and the acceleration of gravity is called g. The two upper equations show that the only gravitational forces are acting upon the particles while the third equation represents the equation of continuity.

HYDRODYNAMIC WAVE EQUATIONS FOR A NON-VISCOUS FLUID ON A RESTING OR ROTATING DISC, AND SOLUTIONS

Quantity	Values for		
	Resting disc or channel	Rotating channel	Rotating disc
$\frac{\partial u}{\partial t}$	$-g\frac{\partial \zeta}{\partial x}$	$-g\frac{\partial \zeta}{\partial x} + 2wv$	$-g\frac{\partial \zeta}{\partial x} + 2wv$
$\frac{\partial v}{\partial t}$	0	$-g\frac{\partial \zeta}{\partial y} - 2wu$	$-2wu$
$\frac{\partial \zeta}{\partial t}$	$-h\frac{\partial u}{\partial x}$	$-h\frac{\partial u}{\partial x}$	$-h\frac{\partial u}{\partial x}$
ζ	$\zeta_0 \sin(\sigma t - \mu x)$	$\zeta_0 e^{-\frac{2w}{c}y} \sin(\sigma t - \mu x)$	$\zeta_0 \sin(\sigma t - \mu x)$
u	$\frac{g}{c}\zeta_0 \sin(\sigma t - \mu x)$	$\frac{g}{c}\zeta_0 e^{-\frac{2w}{c}y} \sin(\sigma t - \mu x)$	$\frac{g}{c}\zeta_0 \frac{\sigma^2}{\sigma^2 - 4w^2} \sin(\sigma t - \mu x)$
v	0	0	$\frac{2w}{\sigma}\frac{g}{c}\zeta_0 \frac{\sigma^2}{\sigma^2 - 4w^2} \cos(\sigma t - \mu x)$
c	$\sqrt{gh}$	$\sqrt{gh}$	$\sqrt{gh}\sqrt{\frac{\sigma^2}{\sigma^2 - 4w^2}}$

Fig. 2.—Hydrodynamic wave equations for a non-viscous fluid on a resting or rotating disc, and solutions.

The first column in the lower part of figure 2 gives a solution of above equations. If the deformation of the surface is represented by a simple sine function, then the velocities of the particles will be directed alternatingly in the direction of progress or against the direction of progress of the wave, the maximum velocity being reached when the wave reaches maximum height. No transversal velocities ($v = 0$) are developed. The wave itself proceeds with a velocity $c = \sqrt{gh}$.

A wave proceeding in an infinitely long rotating channel does not differ very much from the wave here considered. The hydrodynamic equations are more complicated because we now have to add the terms which represent the so-called Corioli's force, namely, the

force of inertia which arises on account of the rotation. The solution of these equations derived by Lord Kelvin is given in the lower part of figure 2. We find now that the amplitude of the wave varies across a section of the channel. The effect of the rotation is evidently to press the wave towards one side of the channel, the forces of inertia arising from the rotation being balanced by a slope of the wave-crest. The velocities of the water-particles are still alternating and the velocity of progress is equal to the square root of gh. These waves can be represented schematically by a simple figure as in figure 3

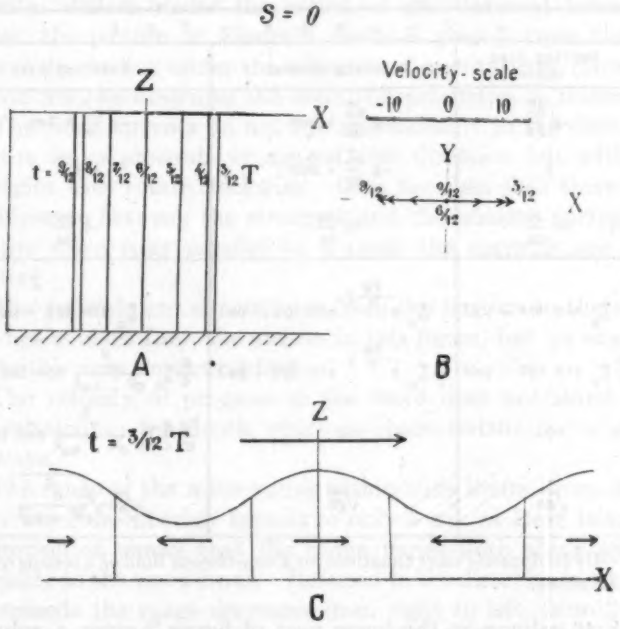

Fig. 3.—Schematic representation of a long wave in a non-viscous fluid on a resting disc or in a rotating channel.

where **A** is to represent a vertical section showing the velocities of the particles in the direction of progress. It is seen that these are uniform from the bottom to the surface. **B** shows that the velocities are alternating. **C** shows a section of the wave with the vertical dimensions extremely exaggerated.

The hydrodynamic wave-equations can also be given a solution with a definite physical meaning when referred to conditions on an unlimited rotating disc. This solution is found in the lower right

part of figure 2. The wave itself is now supposed to have the same character as on a resting disc, the elevation above normal level being supposed to vary in the direction of progress only. The velocities of the particles will then become rotating as is evident from the equations for u and v. The velocity of progress of the wave is also modified becoming greater than on a resting disc. It may here be remarked that the given solution is valid only as long as σ, the frequency of the wave, is smaller than 2ω, the double angular velocity of the disc. Waves of the type here dealt with cannot exist on a rotating disc if this condition is not fulfilled.

The meaning of these results can also be expressed in another way. On a resting plane the orbit of inertia is a straight line but on a rotating disc the orbit of inertia referred to a coordinate system which takes part in the revolution is a circle. The time required for one complete revolution in the circle of inertia is equal to half the time required by the disc for one revolution. If a wave proceeds across a rotating disc we will meet a phenomenon of resonance between the gravitational oscillation and the oscillation in the circle of inertia. The particles will no longer describe straight lines back and forth, but will describe ellipses which will become larger and larger and approach circles more and more as the periodic length of the wave approaches half the time required by the disc for one revolution. At the same time the wave-length will increase, or since the periodic length is assumed to remain constant, the velocity of progress will increase.

On a resting disc one-half of the energy of the wave is present as kinetic energy, the other half as potential. On a rotating disc the forces of inertia tend to preserve the kinetic energy and on an unlimited disc where this tendency is unhindered by boundaries the major part of the energy of the wave will be present as kinetic.

These conditions are represented graphically in figure 4. The vertical section shows that the motion still is uniform from the surface to the bottom, while the horizontal section **B** shows that the velocities have a rotating character.

These two solutions, which are valid for a wave in an infinitely long rotating channel and on an unlimited rotating disc, represent the fundamentals for the discussion of the influence of the Earth's rotation on the tidal wave. We have now to discuss the influence of the eddy-viscosity. It is well known that the viscosity of water is far too small to affect the currents in the sea, but it is also known that if the motion of a fluid is turbulent, then an exchange of mass

takes place between the various layers of the fluid with the result that the fluid appears to have a very great viscosity. We can by dealing with the average velocities introduce a new coefficient, the eddy-viscosity, which has the dimensions of the ordinary coefficient of the viscosity but is from 1,000 to 100,000 times larger. The eddy-

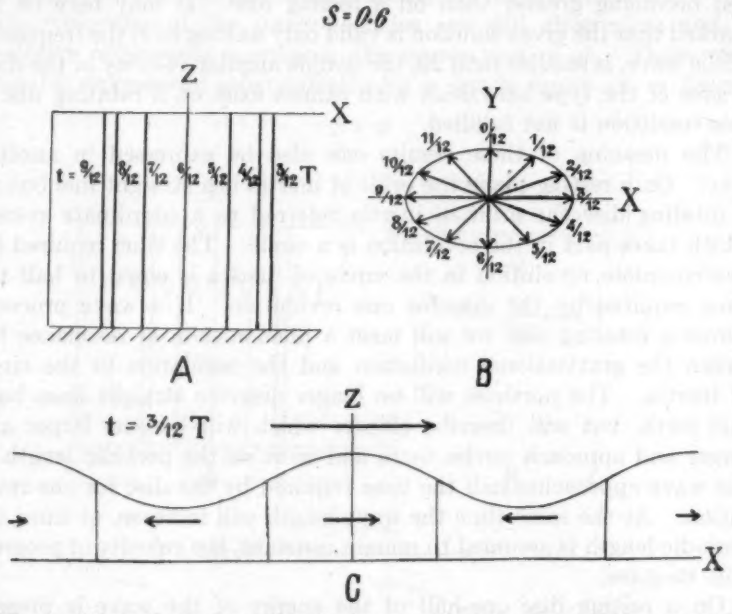

Fig. 4.—Schematic representation of a long wave in a non-viscous fluid on a rotating disc.

viscosity is not constant. It is a measure for the exchange of mass between neighboring layers and the numerical value will therefore depend upon the vertical stability of the layers. However, in the mathematical treatment it is necessary to assume the eddy-viscosity constant, and even then the study of its influence on long waves must be limited to the special case of conditions on an unlimited rotating disc and even then leads to complicated formulae.

Figure 5 shows the hydrodynamic wave-equations for a wave on a rotating disc including the term for the influence of the eddy-viscosity. The equation of continuity now takes the form of an integral equation because the velocities of the particles are no longer uniform from the surface to the bottom. The lower part of the figure gives a solution of these equations. The wave itself now takes the character of a

damped wave, the amplitude decreasing in the direction of progress. The velocities are still rotating but depend upon the vertical coordinate, z; the velocity of progress, c, which can be computed by means of the last equation, is no longer a simple function of the depth but depends also upon the eddy-viscosity. The complex constants C_1 to C_4 have to be determined by the boundary-conditions. Figure 6 illustrates the conditions under certain assumptions. From the vertical section **A** it is seen that the motion is not uniform from the surface to the bottom. The velocity increases from the bottom

HYDRODYNAMIC WAVE EQUATIONS FOR A VISCOUS FLUID ON A ROTATING DISC, AND THEIR SOLUTIONS

$$\frac{\partial u}{\partial t} = -g\frac{\partial \zeta}{\partial x} + 2\omega v + \eta\frac{\partial^2 u}{\partial z^2}$$

$$\frac{\partial v}{\partial t} = \quad - 2\omega u + \eta\frac{\partial^2 v}{\partial z^2}$$

$$\frac{\partial \zeta}{\partial t} = -\int_0^h \frac{\partial u}{\partial x}\,dz$$

$$\zeta = -i\,\zeta_0\, e^{-\gamma x}\, e^{i(\sigma t-\mu x)}$$

$$u = \frac{\sigma}{\sigma^2-4\omega^2}\,g\frac{\zeta_0}{c}\,e^{-\gamma x}(p+1)\left\{C_1 e^{(1+i)\beta_1 z} + C_2 e^{-(1+i)\beta_1 z} + C_3 e^{(1+i)\beta_2 z} + C_4 e^{-(1+i)\beta_2 z} - \sigma\right\} e^{i(\sigma t-\mu x)}$$

$$v = i\frac{\sigma}{\sigma^2-4\omega^2}\,g\frac{\zeta_0}{c}\,e^{-\gamma x}(p+1)\left\{-C_1 e^{(1+i)\beta_1 z} - C_2 e^{-(1+i)\beta_1 z} + C_3 e^{(1+i)\beta_2 z} + C_4 e^{-(1+i)\beta_2 z} - 2\omega\right\} e^{i(\sigma t-\mu x)}$$

$$\frac{\sigma}{\sigma^2-4\omega^2}\,\frac{g}{c^2}\,(p+i)^2\int_0^h \varphi(z)\,dz = 1$$

$$c = \frac{\gamma}{\tau} = \frac{\sigma}{\mu};\quad p = \frac{\gamma}{\mu}$$

Fig. 5.—Hydrodynamic wave equations for a viscous fluid on a rotating disc, and their solutions.

and up and in the vicinity of the bottom the maximum velocity is reached at an earlier moment than at a greater distance from the latter. The horizontal sections for two levels show that the velocities have the rotating character in both levels, but nearer to the bottom the ellipse which joins the ends of the vectors is narrower and turned to the right when referred to orientation of the upper ellipse.

When applying the results of these theoretical considerations to the tidal phenomena on the north Siberian shelf we must remember that the results, strictly speaking, are valid only for waves in a fluid of constant depth and of constant eddy-viscosity on an unlimited rotating disc whereas actual conditions involve a limited region on a rotating sphere with the depth and the eddy-viscosity subject to great variations. Despite this the main features are readily recognized.

Returning to figure 1 we find that the perfect development of the rotary currents at great distance from the coast and the dwindling of the transversal currents, where a coast to the right of the wave prevents their development, is in agreement with what we should expect. The great velocity of progress where the currents are rotating and the small velocity where they are alternating is also in agreement. The great range of the tide which we find where the wave

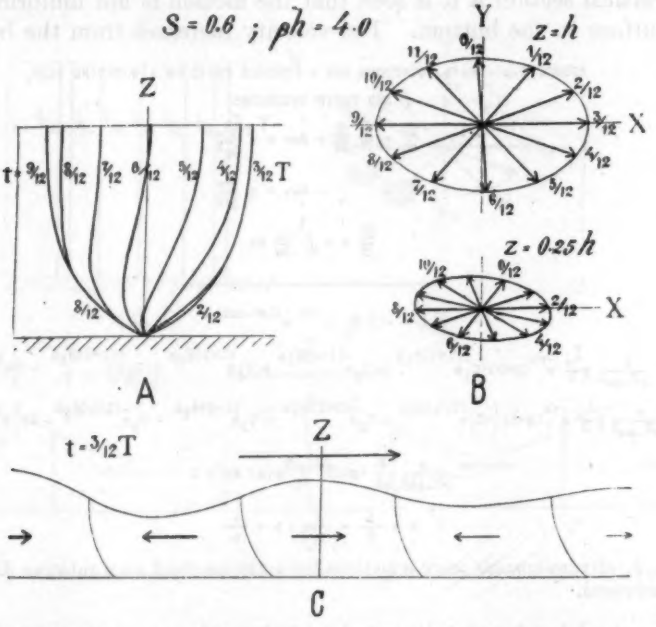

Fig. 6.—Schematic representation of a long wave in a viscous fluid on a rotating disc

rolls along a coast is the result of the wave being pressed against the coast by the deflecting force of the Earth's rotation, while the decrease of the range which accompanies the development of the rotary currents tells that the action of the forces of inertia here tend to preserve the major part of the energy as kinetic. The decrease of the range in the direction of progress is due to the dissipation of the energy through the eddy-viscosity.

I have mentioned that the tidal currents showed great variations with depth. As an example I shall show the currents observed in the central part of the shelf. The upper part of figure 7 shows observed tidal currents. The vertical section **A** represents the com-

ponent of the currents in the supposed direction of progress. The ice took no part in the tidal movement and down to 35 meters the

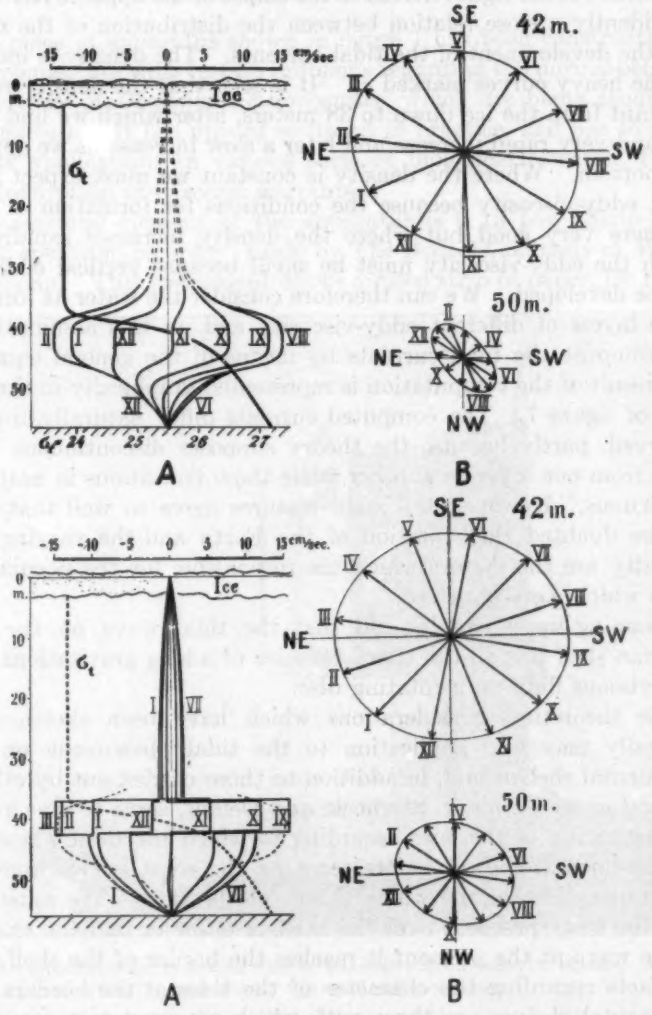

Fig. 7.—Examples of tidal currents observed on the north Siberian shelf (upper part) and theoretically computed tidal currents (lower part).

currents were too weak to be observed. Under this level we found strong tidal currents which again rapidly decreased towards the

bottom. The two horizontal sections show that the currents were rotating in all depths but close to the bottom the ellipse was narrower and turned to the right referred to the ellipse of the upper layer. There is evidently a close relation between the distribution of the density and the development of the tidal currents. The density is indicated by the heavy curves marked σ_t. It is seen that the density remains constant from the ice down to 38 meters, after which we find a sudden and very rapid increase and later a slow increase as we approach the bottom. Where the density is constant we must expect a very great eddy-viscosity because the conditions for formation of eddies are here very good but where the density increases rapidly with depth the eddy-viscosity must be small because vertical eddies can not be developed. We can therefore consider the water as formed of three layers of different eddy-viscosity and on this assumption we can compute the tidal currents by means of the general equations. The result of the computation is represented graphically in the lower part of figure 7. The computed currents differ naturally from the observed, partly because the theory supposes discontinuous transitions from one layer to another while these transitions in nature are continuous. However, the main features agree so well that it can not be doubted that rotation of the Earth and the varying eddy-viscosity are the factors which are responsible for the peculiar currents which were observed.

Summing up it can be said that the tidal wave on the north Siberian shelf has all the characteristics of a long gravitational wave in a viscous fluid on a rotating disc.

The theoretical considerations which have been sketched here naturally may find application to the tidal phenomena on other continental shelves and, in addition to those carried out by other investigators as Taylor, v. Sterneck, and Defant, serve to give a better understanding of the laws according to which the tidal waves cross the continental shelves before reaching the coast. This knowledge is indispensable for the whole theory of the tides. We must know how the wave proceeds over the shelf in order to find the character of the wave at the moment it reaches the border of the shelf. And the facts regarding the character of the tides at the borders of the continental shelves are those with which we must test any theory dealing with the fundamental but exceedingly difficult problem, namely, the creation of the tidal waves in the big oceans under the action of the tidal creating forces.

BIOLOGY.—*A time recorder for quantitative work in animal behavior.*[1] RAYMOND PEARL, Institute for Biological Research of the Johns Hopkins University.

The piece of apparatus shown in figure 1 has been constructed for use in connection with certain problems regarding the normal behavior and activity of *Drosophila melanogaster*, which are being studied in this Institute. It has proved so useful in practice, and has so many obvious applications in various sorts of biological research, that a brief description of it seems warranted.

The essential element of the apparatus is a 15 pen "Strip chart electric operation recorder" made by The Bristol Company of Waterbury, Conn. This instrument draws a ruled strip of paper, by means

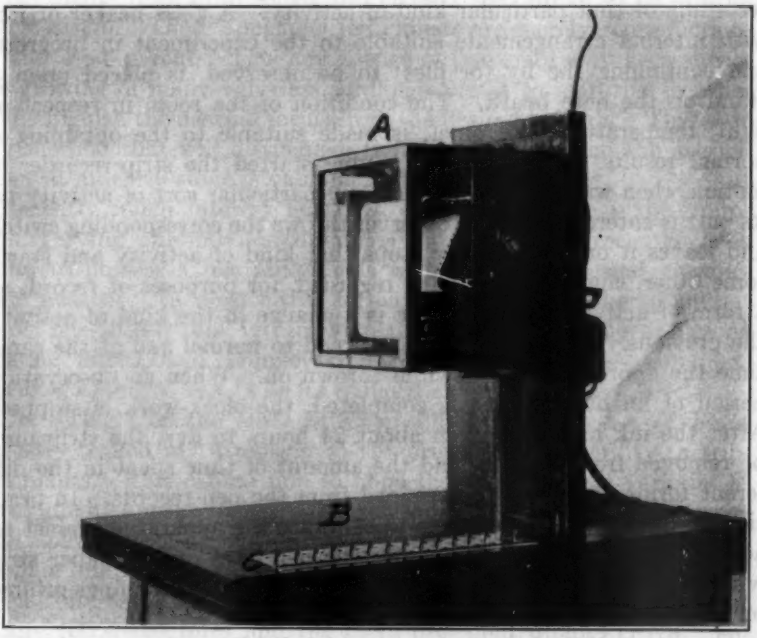

Fig. 1.—Apparatus for recording time relations in animal behavior studies. A, strip chart electric recorder. B, base board. C, row of radio switches.

of an accurate clockwork, under the 15 pens at a constant rate of speed. By suitable adjustments of the mechanism this rate may be as slow as one inch per hour, or as fast as 6 inches per minute, with a

[1] Received Oct. 26, 1926.

number of intermediate speeds. Each pen is controlled by a small relay magnet, in such a way that when a current is passed through the coil of the magnet the end of the pen is drawn about 1 mm. to the side of its normal resting position. In the apparatus shown in figure 1, each of the pens of the operation recorder has been wired to a small radio switch set in the base board. Therefore the path of each pen is controllable separately by throwing the appropriate switch in this series.

The manner in which we have used the apparatus is this. On a strip of white adhesive tape alongside the row of switches are written catchwords for the different categories of activity in which a *Drosophila* indulges, such as "flying," "walking," "cleaning forelegs," etc. The switch opposite each such designation is devoted to the recording of that particular kind of activity. A glass beaker or jar, with internal arrangements suitable to the experiment in progress, and containing the fly (or flies) to be observed, is placed upon a stand on the base board. The condition of the room in respect of light, temperature, and quiet, is made suitable to the obtaining of normal results. The observer, having started the strip recorder in motion, then watches the fly. As any particular sort of activity on its part is entered upon, the observer throws the corresponding switch and leaves it on until the fly stops that kind of activity and starts some other, complete rest being regarded, for purposes of record, as a form of activity. When there is a change in the kind of activity the previously thrown switch is returned to normal and at the same time the appropriate new switch thrown on. When an observation period of an hour or two is completed, the clock-work is stopped. After the ink has been given about 24 hours to dry, the strip may be removed from the roll, and the amount of time spent in the different forms of activity determined from the pen records. In practice we have found it desirable to calibrate the apparatus against an accurate stop watch, and measure the pen lines on the paper strip with a millimeter rule, rather than to depend upon the rulings printed on the paper and the stated clock rate.

The dimensions of the apparatus shown in figure 1 are as follows: Length of base board, 86 cm.; width of base board, 51 cm.; height of upright, 60 cm.; width of upright, 29 cm.

On the back of the upright board are a resistance box, a knife switch in the lead-in line, and a fuse block. These are merely for the purpose of establishing a safe connection with the lighting circuit of the laboratory.

Besides the use of this apparatus described in detail above we have employed it for various other physiological and behavior observations, in which it was essential to record the time relations. It would seem to have a wide range of applicability in biological work.

GENETICS.—*Triploid citrus.*[1] A. E. LONGLEY, Bureau of Plant Industry. (Communicated by G. N. COLLINS.)

The work of producing new types of citrus fruits by hybridization is seriously handicapped by the presence of nucellar embryos in the seed. Swingle's[2] early work showed that many citrus hybrids produce only apogamic progeny when selfed. More recently Frost[3] in his genetic studies of citrus seedlings finds that a large percentage of his plants from both selfed and crossed seed prove to be of apogamic origin. These apogamic individuals are merely reproductions of the seed parent. This prevalence of polyembryony necessitates the growing of many valueless seedlings almost to maturity in order to distinguish the asexual forms from the desired hybrids. Therefore any method that will distinguish the true hybrids from the asexual forms at an early stage is valuable.

Recently much interest has been awakened in the plant groups with varying chromosome numbers and citrus has recently been found to possess a few individuals with double the usual chromosome number. In most citrus forms the haploid number is 9, but Frost[4] has shown that tetraploid plants occasionally appear among seedling citrus, and Longley[5] found that the Chinese kumquat, *Fortunella hindsii*, has 18 as its reduced chromosome number.

Dr. Swingle of the office of Crop Physiology, Bureau of Plant Industry, called my attention to the prevalence of sterility in triploid plants. This caused him to hope that new seedless varieties of citrus might appear in this aberrant group. Since a cross between a tetraploid and a diploid should produce triploids, i.e., have a chromosome number intermediate between the two parent forms, a special interest is attached to crosses between this Chinese kumquat or any tetraploid form and the more prevalent diploid citrus.

[1] Received Oct. 16, 1926.

[2] SWINGLE, W. T. *New types of citrus fruits for Florida.* Proc. Florida State Hort. Soc. **23**: 36–41, illus. 1910.

[3] FROST, H. B. *Polyembryony, heterozygosis and chimera in citrus.* Hilgardia **1**: 365–402, illust. 1926.

[4] FROST, H. B. *Tetraploidy in Citrus.* Proc. Nat. Acad. Sci. **11**: 535–537, illus. 1925.

[5] LONGLEY, A. E. *Polycary, polyspory and polyploidy in citrus and citrus relatives.* Journ. Wash. Acad. Sci. **15**: 347–351, illus. 1925.

In Dr. Swingle's extensive collection of bigeneric citrus hybrids there were three young plants, the result of crossing a limequat, *Fortunella margarita* × *Citrus aurantifolia*, with *Fortunella hindsii*. Although to the trained eye there was evidence of a dual parentage, it was realized that they might be the result of nucellar buds. As a means of distinguishing between a true hybrid and a plant of apogamic origin the author attempted a determination of the chromosome numbers in these plants.

The first flower buds that appeared were collected at the stage when the pollen mother cells were undergoing the reduction divisions.

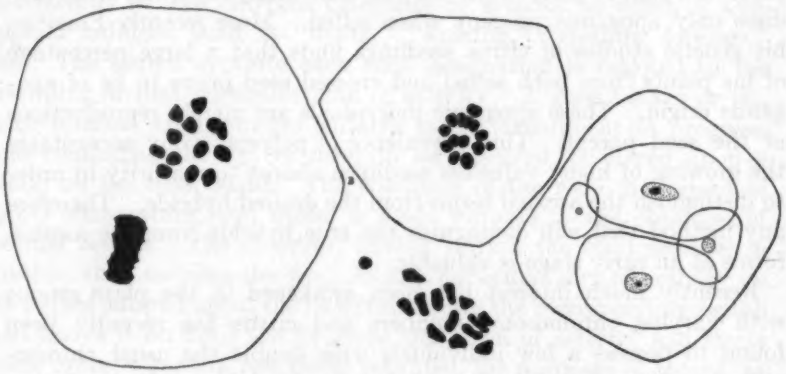

Fig. 1.—Pollen development in limequat (*Fortunella margarita* × *Citra aurantifolia*) × *Fortunella hindsii*. A, Homotypic metaphase, 13 chromosomes showing in one plate (×2000). B and C, Heterotypic metaphase, 13 bivalent and one univalent chromosome (×650). D, An abnormal pollen tetrad (×650). (Figures drawn with the aid of a camera lucida, using a Leitz 1.5 objective, and for A a ×18 ocular, for B, C and D a ×15 ocular. Reduced about ⅓ in reproduction.)

The anthers were opened in acetocarmine solution and counts were made as soon as the chromosomes were sufficiently differentiated from the surrounding plasma to make determinations possible.

The first counts were made from cells in the metaphase of the homotypic division. Figure 1 A shows one plate with 13 chromosomes. Unfortunately no counts could be made of two plates in the same cell and, although 13 stands intermediate between the diploid and tetraploid numbers, it required additional counts to settle definitely the chromosome number of this plant. Months later other buds from this plant were available and figure 1, B and C, are drawings of the chromosomes in the metaphase of the heterotypic division. Both figures show 13 bivalent and a single univalent chromosome. Such clear figures were not often met with. Frequently the

chromosomes were clumped together into what appeared to be trivalents, and at other times pairing failed causing several univalents to be present at diakinesis. The chromosomes of citrus are very small and it was almost impossible to distinguish between large bivalent and trivalent chromosomes. It was only from such clear figures as are pictured that satisfactory counts could be made. Many counts, however, have assured me that the plant studied is a trivalent citrus and represents a cross.

A few tetrads were studied (figure 1 D) in order to determine the prevalence of polyspory. It was found that about 17 per cent had five and 1.5 per cent had six grains in a pollen tetrad. These counts and the presence of only a small percentage of abnormal appearing grains in mature pollen indicate that very little irregularity in chromosome distribution occurs during meiosis in this triploid plant.

The finding of this triploid hybrid shows that it is possible to produce triploid citrus by appropriate crosses. It is, moreover, hoped that in this or similar crosses the much desired seedless Kumquat will be produced.

BOTANY.—*New species of cotton from Colombia and Ecuador.*[1] O. F. COOK and J. W. HUBBARD, Bureau of Plant Industry.

The wealth of natural forms in the genus *Gossypium* receives further illustration in new types of cotton plants collected recently in several localities on the west coast of South America, in Colombia and Ecuador. The native cottons of this region apparently are not closely related to the series of Mexican species described in this JOURNAL under date of June 19, 1926, but show other peculiar characters not previously recognized among the species of *Gossypium*.

The new features include specializations of the involucral bracts and extrafloral nectaries, as well as of the leaves, bolls and seeds. One of new species has involucres with the margins of the bracts turned outward, so that the buds and young bolls are exposed, while another has very small involucres, and very narrow bracts, with only 3 to 5 teeth. In striking contrast with such involucres, other South American species have very large many-toothed bracts, cordate at base, with broad auricles united along their inner margins or overlapping across the pedicel. Other outstanding features are very large and prominent involucral nectaries, large auriform crests or expanded bractlet-like organs surrounding the base of the calyx, bolls

[1] Received Oct. 16, 1926.

with large numbers of seeds per lock, bolls with only 2 locks, the absence of simple or 3-lobed leaves, and pubescence of simple hairs, instead of the stellate pubescence usual in *Gossypium*. Descriptions of some of these characters, with natural-size photographs of their occurrence in the different species, have been prepared for the Journal of Heredity, to follow the paper on characters of new cottons from Mexico which is being printed in the Journal of Heredity for November, 1926. While most of the tropical cottons are not adapted to conditions in the United States, it is of interest and importance to breeding to know the range of characters represented in the genus.

The need of basing botanical descriptions of cotton plants on the living material, growing under conditions of natural adaptation, as explained in the previous paper, becomes still more obvious after the study of these South American forms. Some of the most striking and distinctive characters could not be recognized or described from dried specimens, though some can be shown in photographs. Several important differences of leaves and involucres must be treated in three dimensions, not merely in terms of size and outline. The pressing of the specimens obliterates some of the most distinctive positional features.

Some of the native cottons of the northern districts of Peru were described by Richard Spruce,[2] in a paper published in 1865, but the species were not named and apparently are not the same as those here described. No other botanist appears to have observed and recorded the characters of cotton plants in South America from living material.

Key to Species Here Described

Involucral bracts very small and narrow, with a strong flexure or stand-off at base and with few marginal teeth, only 3 to 5; bolls mostly 4-locked, nearly round, the apex blunt or retuse, surface nearly uniform light green, the oil-glands deeply immersed in the green tissue; pubescence of simple hairs; seeds fuzzy: *Gossypium tridens*.

Involucral bracts large and broad, with a slight basal flexure, marginal teeth numerous, 9 to 19; bolls mostly 3-locked, oval, ovate, or fusiform, acuminate or apiculate, deeply pitted, exposing the black oil-glands distinctly; pubescence of stellate hairs; seeds nearly naked after removal of lint, the fuzz very thin or confined to small tufts or bands.....

Involucres with small nectaries, located in slight depressions; leaf nectaries small, usually confined to the midvein even on large 7-lobed leaves of the main stalk or vegetative branches; fruiting branch leaves all 5-lobed; bolls oblong-oval, abruptly acuminate, the surface even, the oil-gland punctations small and scattering: *Gossypium quinacre*.

[2] Spruce, Richard. *The culture of cotton in northern Peru*, The Technologist, May 1, 1865, pp. 431–445.

Involucres with large, prominent nectaries; leaf nectaries often large, commonly 3 on large 5-lobed and 7-lobed leaves of the main stalk and vegetative branches; fruiting branch leaves commonly 3-lobed; bolls conic-oval, acuminate, the surface irregular with large pits which are often crowded or confluent.....

Involucral bracts with margins strongly everted, exposing the buds and young bolls; seeds with lint confined to the upper half or two-thirds of the surface, and with little or no fuzz except in a short band in the lower part of the lint area: *Gossypium evertum*.

Involucral bracts with plane margins, inclosing the buds and young bolls; seeds with tufts of fuzz at the base or apex.....

Inner nectaries large, longer than broad, connected by large auriform processes or crests extending around the base of the calyx; auricles of bract moderately developed, united at base, not overlapping the pedicel: *Gossypium calycotum*.

Inner nectaries broader than long; not connected by processes or crests, rarely subtended by narrow bractlets; auricles of the bracts very large, the inner margins curved inward, overlapping across the pedicel, forming circles around the outer nectaries; bolls ovate-oblong, abruptly acuminate: *Gossypium auritum*.

Gossypium tridens sp. nov.

Plant large and tree-like, about 15 feet in height with an erect trunk 4 inches in diameter at base, light green open foliage, and rather long fruiting branches, the numerous short joints bearing small rounded bolls, often with 6 to 8 bolls on a branch.

Leaves small, simple or with 2 to 5 lobes, usually 3-lobed on vegetative branches and 2-lobed on fruiting branches; simple and 5-lobed leaves very few; lobes rather long, narrow, acuminate; midlobe[3] slightly constricted, upfolded around the sinus; forelobes usually unequal, one often twice as large as the other; auricles very short, the basal sinus open; callus strongly decurrent; surface of leaves entirely glabrous, with a fringe of hairs on the margins and scattering hairs on the larger veins above and below; petioles and young branches rather densely pilose; hairs mostly simple, rarely two or three together, instead of stellate; pubescence very persistent, remaining on the year-old wood; length on the midvein of large 5-lobed leaf 16 cm., on the greatest expansion of auricle 17.5 cm., width on points of forelobes 23 cm., on points of sidelobes 13.5 cm., length of petiole 9.5 cm., leaf nectary single, rather small, with prominent rim, oval or ovate, about 1 cm. from base of vein; stipules fugacious, small, falcate, about 1 cm. long, 1 mm. wide at bas e those of fruiting branches shorter and broader.

Involucral bracts very small and narrow, sublanceolate, slightly auriculate, with strong flexures or off-sets at base; usually free, but sometimes connected for about 1 mm.; teeth usually 3, sometimes 4 or 5, the median tooth as long or longer than the body of the bract, with one or two small teeth on each side; bractlets not present; pedicels cylindrical, short, solid, triangular only near receptacle. Outer nectaries broadly oval or transverse, sunken; inner nectaries very broadly triangular, often reduced to a transverse slit. Calyx very short, with shallow rounded lobes; flowers not seen.

[3] To designate the successive lobes of the leaves, beginning at the middle, the terms midlobe, forelobes, sidelobes and backlobes are used. The principal veins of the lobes are designated correspondingly as midvein, foreveins, sideveins and backveins.

Bolls small, usually as broad as long, subrotund, abruptly narrowed to a blunt point or with a small apical depression; fissures deeply marked at the tip, the divisions bulging beyond the insertion of the stigma; surface smooth, light green, with shallow punctations, the oil-glands deeply immersed; locks 3 and 4, usually 4, seeds per lock 5 to 7.

Seed small, densely covered with long greenish fuzz; lint white, about 1 inch long, fine and silky, not fluffing out.

Type in U. S. National Herbarium nos. 1,282,030, 1,282,031, and 1,282,032 collected from the same plant at Buenaventura, Colombia, May 28, 1926, by O. F. Cook and J. W. Hubbard (no. 169).

The outstanding features of this plant are the small, narrow, free, involucral bracts, the small round bolls, the numerous 2-lobed leaves, and the pubescence of simple hairs.

Gossypium quinacre sp. nov.

Plant moderately robust, about 2 meters high, of rather low, spreading "herbaceous" habit, main stalk short-jointed, bearing numerous short-jointed horizontal vegetative branches, and strong fruiting branches, attaining 85 cm., with rather long basal joints; also with fruiting branches near the ground on the vegetative branches; foliage and general appearance of the plant suggesting Sea Island cotton.

Leaves large, subglabrous, with pale venation, surface strongly upfolded between veins; lobes 5 to 7, with long acuminate points, none of the leaves 3-lobed; the forelobes often equal to the midlobe; auricles large, usually overlapping; midlobes occasionally with teeth, but these confined to a few leaves of the main stalk, the teeth usually above the middle of the lobes; length of large leaf on midvein 23 cm., on greatest expansion of auricle 25 cm., width on points of forelobes, 33 cm., on points of sidelobes 26 cm., length of petiole 16 cm. Leaf nectaries, only 1 on fruiting branch leaves, 1 to 3 on main stalk and vegetative branch leaves, even large 7-lobed leaves sometimes with only 1 nectary; midvein nectaries long, elliptical to lanceolate, located about 2 cm. from base, forevein nectaries very small, ovate, located about 1 cm. from base. Petioles papillate with prominent oil-gland. Stipules long, linear, but on fruiting branches sometimes broad and strongly curved, occasionally bidentate.

Involucral bracts very large, ovate, deeply cordate, the auricles slightly curved inward, but not overlapping; the short inner margins united, usually for only 1 or 2 mm., sometimes for 4 or 5 mm.; teeth 13 to 19, very long and slender, attaining 3.5 cm. on bracts with total length of 8 cm.; three middle teeth not prominent, margins of auricles entire; bractlets of common occurrence; outer nectaries prominent, subrotund; inner nectaries subtriangular; pedicels rather short, attaining 3.5 cm., triangular, with deep grooves running down the angles, making six nearly equal grooves and ridges; calyx short, with five very shallow sinuate lobes.

Flowers very large, not opened beyond a cylinder, 9 to 9.5 cm. from the outer nectary to end of corolla; petals pale yellow, with small petal spots.

Bolls oblong-oval, abruptly acuminate, 3-locked or often only 2-locked, the surface somewhat lighter green, smoother and more even, and with smaller and more scattered punctations than in related species; mature open bolls not present.

Type in U. S. National Herbarium nos. 1,282,039, 1,282,040, and 1,282,041,

collected from a single plant at Bahia de Caraquez, Ecuador, May 12, 1926, by O. F. Cook and J. W. Hubbard (no. 112).

The plant grew among ivory-nut shells, and was so healthy and vigorous that a full development of vegetative branches would be expected, as well as full numbers of leaf-lobes, nectaries, and carpels, so that the peculiarities in such characters appear significant. The vegetative branches, though numerous, did not behave like the erect or strongly ascending, stiff woody shoots of the "tree" cottons, but showed a modified fruiting habit, soon spreading into horizontal or decumbent positions, with flowers and bolls near the ground, like a cultivated "annual" or "herbaceous" type of cotton. There were 18 vegetative branches, the lower about 1.5 meters long, the upper 1 meter, also vegetative shoots on some of the lower fruiting branches, from the basal or second joints. On a fruiting branch 85 cm. long, eight successive joints measured in centimeters as follows: 22, 10, 10, 9, 9, 10, 10, 3. The main stalk internodes and those of the vegetative branches were 4 to 5 cm. long.

The outstanding features are the spreading low-fruiting habit, the absence of 3-lobed leaves, the slight development of nectaries, both on the leaves and the involucres, the narrow oblong bolls, often with only 2 locks; and the very large involucral bracts greatly exceeding the bolls, with the teeth very numerous and long, and with the auricles deep and broad. Considered as a member of the South American series, the characters presented by this plant may afford an indication of the relationship of the Sea Island type of cotton.

Since only one plant of this type was seen, it may have been a hybrid, but it presents such an interesting series of characters that a description seems warranted. The large leaves and bracts, and the narrow, few-locked bolls, are not inconsistent with hybridism, but the rather spreading habit and the specialized character of the vegetative branches, short-jointed, and producing numerous fruiting branches near the ground, do not suggest a hybrid.

Gossypium evertum sp. nov.

Plants large and spreading, attaining a height of 10 or 12 feet, with stalks 3 or 4 inches in diameter at base; foliage dense, light green, glabrous; fruiting branches many-jointed, the basal joint usually long, from 12 to 18 cm., other joints from 2 to 5 cm.

Leaves a rather light, fresh-green, glabrescent; very young leaves sparingly covered with short stellate hairs below; lobes 3 to 5, usually 5, rather long, with long-acuminate points; sidelobes usually at right angles to the midlobes; auricles short, sinus open, basal curves or margins of the auricles often distinctly undulate; veins pale, prominent below; surface often bullate between veins near base; length of large 5-lobed leaf, on the midvein 18.5 cm., on the greatest expansion of the auricle 21 cm., width on points of forelobes 28 cm., width on points of sidelobes 20 cm.; leaf nectaries small, usually 3 on leaves of the main stalk and vegetative branches, but only one on leaves of fruiting branches; nectaries of the midveins rather large and deep,

with prominent rims, located about 1.5 cm. from base; nectaries of foreveins very small, 3 to 5 mm. from base, usually ovate or oval, sometimes reduced to a small narrow groove; stipules large, linear, fugacious, usually shorter and broader on the fruiting branches, often very irregular and unequal, one of a pair sometimes twice as large as the other.

Involucres light green, glabrous; bracts oval or ovate, subcordate, strongly concave or everted, exposing much of the inner surface, which is pale green and glossy; teeth 9 to 13, irregularly arranged, the 3 middle teeth not prominent; auricles very short, with entire margins, the inner margins regularly united; no trace of bractlets found; outer nectaries rather large, rounded or transversely oval, prominent above the surrounding surface, especially before flowering; inner nectaries rather large subtriangular; pedicels short, distinctly triangular, with a small groove running down each ridge; calyx, truncate or with only slight indications of lobing.

Flowers large, cylindrical, not opening widely; petals broad and widely overlapping, with a distinct lateral lobe or tooth at the point of the section exposed in the bud, pale yellow with small red petal spots and numerous golden yellow oil-glands, the venation very distinct; staminal column 2.5 cm. long, with small scattering yellow oil-glands; stamens not numerous, filaments rather short, in five distinct rows; anthers pale, medium size, pollen deep yellow; style long, stigma exserted about 1 cm.; oil-glands of styles in two widely spaced rows, the glands in one row alternating with those in the other.

Bolls 3-locked, about 5 cm. long by 2 cm. wide, narrowly conic-oval, acuminate, oil-glands large and scattering, surface slightly rugose, shining; ripe bolls open widely, the points curving backward, forming sharp hooks; seeds per lock 7.

Seed small, dark brown, naked at the base or nearly so, with a narrow band of short brownish fuzz near the middle, and sometimes small tufts of fuzz at either end; lint faintly tinged with buff, about 1¼ inches in length, slightly harsh; the lint is confined to the upper portion of the seed, from the band of fuzz to the tip.

Type in U. S. National Herbarium nos. 1,282,028 and 1,282,029, collected at Buenaventura, Colombia, April 30, 1926, by O. F. Cook and J. W. Hubbard (no. 63).

The distinctive characters are the light, fresh-green glabrous foliage, the strongly everted involucre, the lateral petal tooth and the distribution of fuzz and lint on the seed. The lower part of seed usually is entirely naked, the fuzz mostly restricted to a belt around the seed, where the lint begins.

The open involucres, with strongly everted bracts, may be considered as an adaptation to a humid tropical climate. Closed involucres appear disadvantageous, especially under humid conditions, because of the protection afforded to insect pests and plant diseases. Diseases like anthracnose and bacterial boll-rot are very common and destructive in tropical America.

Gossypium calycotum sp. nov.

Plants large, spreading, 8 to 10 feet high, the large fruiting branches with long basal joints like Egyptian cotton, though the foliage appears more like Upland cotton.

Leaves light green, simple or 3 to 5 lobed, the upper surface subglabrous, the lower surface rather densely covered with very short stellate or tufted

hairs; lobes rather short, subtriangular, acuminate, sidelobes often represented only by a tooth; sinus between lobes rounded and open, the surface of the leaf usually flat; sidelobes often extending backward at an angle of about 50 or 60 degrees to the midvein and closing the basal sinus, though the auricles are rather short; length of blade on midvein 19 cm., on greatest expansion of auricle 24 cm., width on points of forelobes 30 cm., on points of sidelobes 20.5 cm.; veins prominent below; nectaries usually 3, appearing as long narrow slits, those on midvein located about 2 cm. from base, and attaining about 5 mm. in length, about twice as large as those on foreveins; petioles papillate, especially near base of leaf; stipules rather large, fugacious, very broad and strongly curved on fruiting branches, often broader than long, sometimes toothed.

Involucral bracts large, with 10 to 13 rather large teeth; at base cordate with an abrupt, deep sinus formed by the straight united inner margins of the auricles extending back along the pedicel for 8 to 10 mm.; lower margins open and slightly flared, forming nearly a right angle with the inner margins, lateral margins entire, often to the middle of the bracts; calyx rather short, subtruncate, with very slight indications of lobing; pedicels short, stout, triangular, 2 to 2.5 cm. long; outer nectaries subrotund, rather large, prominent, inner nectaries subtriangular or trapezoidal, usually slightly longer than broad; large auriform crests subtending and connecting the inner nectaries, the crests appearing occasionally like bractlets, but usually as ruffle-like appendages irregularly curled or rolled outward, extending around the base of the calyx, the bractlet-like crests apparently of the same texture as the calyx, with numerous small black oil-glands, but the more continuous crests with lower surface very pale and usually without oil-glands. Flowers not seen.

Bolls of medium size, attaining 5 cm. long, rather broadly conic-ovoid, with stout acuminate points, the surface rather closely and irregularly pitted; locks 3, with 9 or 10 seeds per lock.

Seeds dark brown, with a small tuft of light brown fuzz at base. Lint white, about 1¼ inches long.

Type in U. S. National Herbarium nos. 1,282,033, 1,282,034, and 1,282,035, collected from a single plant at Esmeraldas, Ecuador, May 11, 1926, by O. F. Cook and J. W. Hubbard (no. 105).

The remarkable broad auriform crests extending around the base of the calyx between the inner nectaries are the outstanding feature of this species. The crests are not parallel to the insertions of the bracts, but rise rapidly, usually to about half the height of the calyx, and sometimes to the full height, forming a semicircle between two of the inner nectaries. In many cases the crests are interrupted and occur as small separate sections between the nectaries, but always on a curve, like a complete crest. Below the complete crests the surface of the calyx is pale and without oil-glands.

Gossypium auritum sp. nov.

A large spreading perennial shrub, attaining 8 to 10 feet in height and 3 to 4 inches in diameter at base, the large fruiting branches with long basal joints, often attaining 18 to 20 cm.; foliage deep green, subglabrous.

Leaves large, usually with 5 lobes, even on rather small leaves; midlobes large, ovate, oblong, abruptly acuminate, often apiculate; the forelobes large sometimes nearly equal to the midlobes; the sidelobes usually short,

broadly triangular; auricles ample, often overlapping; texture rather heavy, upper surface glabrous, strongly upfolded between the bases of the primary veins; callus and veins whitish, lower surface pale green, with few stellate hairs; length of large leaf on midvein 19 cm., on the greatest expansion of the auricle 24 cm., width on points of forelobes 30 cm., width on points of sidelobes 23 cm.; leaf nectaries short, broadly ovate or cordate, sometimes 3, usually only one even on large 5-lobed leaves, inserted low on the midvein, often 1 cm. or less from the base, nectaries of foreveins sometimes only 3 to 4 mm. from the base; petioles long, stout, attaining 21 cm. in length, with a distinct pulvinus at each end, the upper pulvinus papillate; stipules large, fugacious, linear on vegetative branches, much broader on fruiting branches, sometimes nearly as broad as long, and strongly curved, occasionally bidentate.

Involucral bracts large, subrotund, broadly ovate; the auricles unusually large and broad, united only slightly at base, the inner margin strongly curved, meeting or overlapping across the pedicel, thus forming a complete circle around the outer nectary; teeth rather small, usually 17, sometimes 19 or 20, the margins of the auricles entire; bractlets often present; outer nectaries very large, prominent, cuneate, inner nectaries large, triangular, with a border of black oil-glands; calyx with five distinct, very short, rounded lobes.

Flowers large, 7 to 8 cm. long, the petals pale yellow, with small petal spots; staminal column rather long, about 2.8 cm., naked section at base about 8 mm.; stamens numerous, filaments short, anthers small, light brownish; stigma exserted about 5 mm. above stamens, the apex divided for about 3 mm. into 3 distinct lobes.

Bolls large, attaining 6.5 cm. by 3 cm., ovate-oblong, abruptly acuminate; usually 3-locked, sometimes 4-locked, with 12 or 13 seeds per lock; fissures deeply grooved near the tip; surface rather dark green, shining, rather coarsely and deeply punctate, with the oil-glands distinct.

Seed small, brown, gradually narrowed to a sharp beak, with a long spur on the funicle, the raphe often quite prominent, irregularly covered with short brownish fuzz, usually longer and more dense towards each end, with irregular patches near center, in places almost naked; lint white, very fine, silky, about 1¼ inches long, but rather sparse and uneven.

Type in U. S. National Herbarium nos. 1,282,036, 1,282,037, and 1,282,038, collected from a single plant at Esmeraldas, Ecuador, May 11, 1926, by O. F. Cook and J. W. Hubbard (no. 108). Specimens and photographs were also secured from a large plant in a door yard at Bahia de Caraquez, Ecuador.

The outstanding characters of the species are the deep broad auricles and numerous teeth of the involucral bracts, and the large 3-locked bolls containing 12 or 13 seeds per lock. The inner margins of the bract auricles often overlap across the pedicel, thus forming complete circles around the outer nectaries.

Several characters of this species suggest the Ica cotton described by Spruce from northern Peru, particularly the large bolls and the large numbers of seeds in each lock, but the bracts of the Ica cotton are described as "laciniate all round the margin," and the outer nectaries as "obsolete."